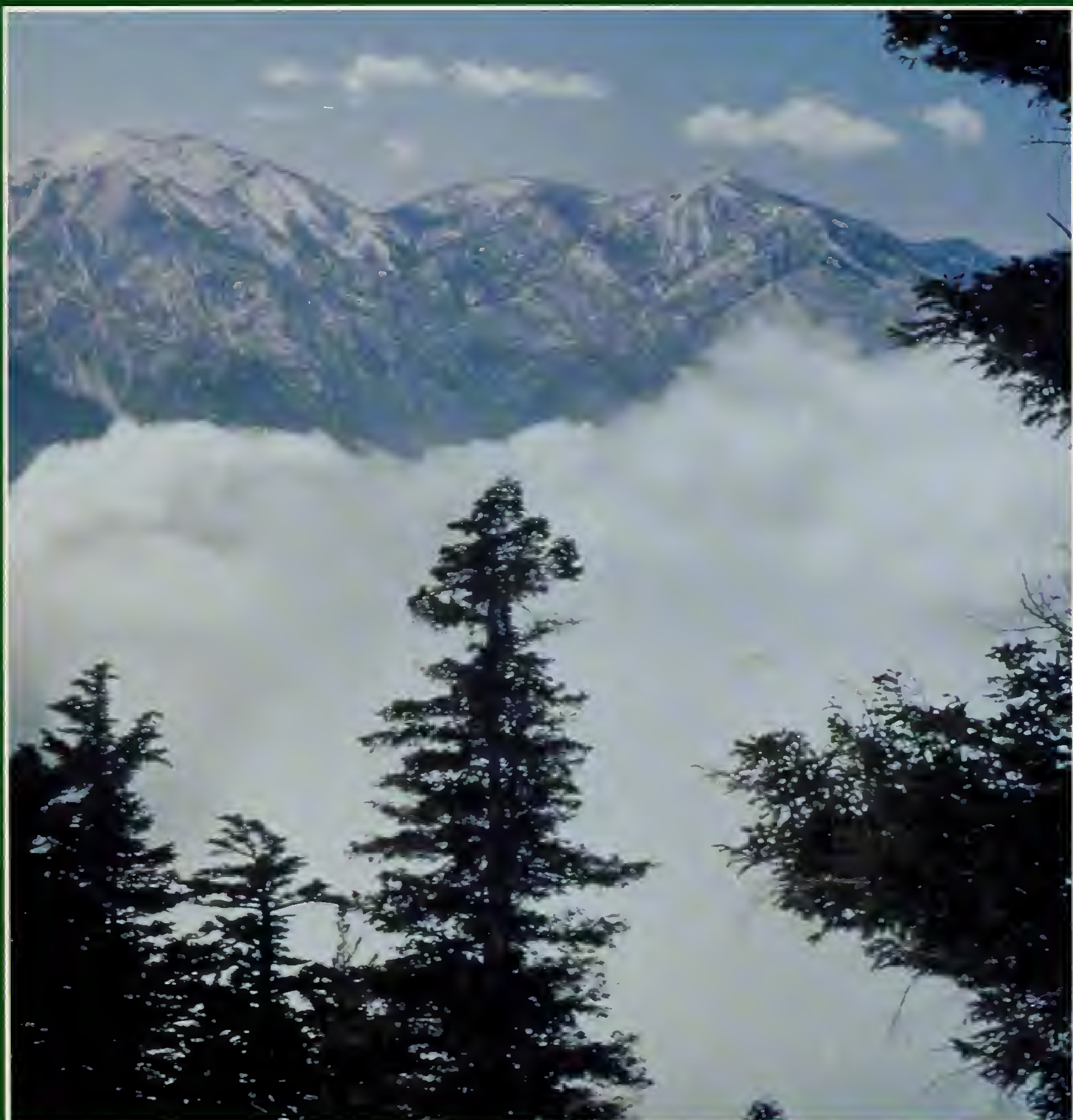
FOREST SERVICE

GLOBAL CHANGE RESEARCH PROGRAM



United States Department of Agriculture • Forest Service
October 1992

FOREST SERVICE

GLOBAL CHANGE RESEARCH PROGRAM

PROGRAM PLAN UPDATE

USDA Forest Service
October 1992
PA-1497

Contents

Foreword: Natural Resources Management in an Era of Global Change v

Executive Summary vii

I. GLOBAL CHANGE AND THE USDA FOREST SERVICE 1

II. NATIONAL RESEARCH PROGRAM ELEMENTS 3
- Atmosphere/Biosphere Gas and Energy Exchange Research (ATBIOX) 3
- Disturbance Ecology Research (DISTUR) 4
- Ecosystem Dynamics Research (ECODYN) 6
- Human Activities and Natural Resources Interactions Research (HUMANI) 7
- Assessment and Future Milestones 8

III. REGIONAL RESEARCH PROGRAMS 11
- Pacific Global Change Program 11
- Interior West Global Change Program 15
- Forest Products Laboratory 17
- Northern Global Change Program 19
- Southern Global Change Program 23

IV. MODELING
- Objectives 27
- Scope 28

V. GLOBAL CHANGE AND RESOURCE MONITORING 29

VI. DATA QUALITY ASSESSMENT 31

VII. GLOBAL CHANGE AND RESOURCE PLANNING ACT ASSESSMENTS
- Global Change Assessments 33
- RPA Assessments 34
- Linkages Between Global Change and RPA 34

Foreword: Natural Resources Management in an Era of Global Change

The international science community has issued a series of predictions of global atmospheric change that, if correct, will have heretofore unexperienced impact on our forests. Convincing the public and their natural resource managers to respond to these effects must be high on the agenda of the science community. The responses we examine and propose, however, should stem from an understanding of the evolving role of the natural resource manager and how that role might be affected by global change.

Forest management has its roots in the conservation and manipulation of forest wildlife habitat for hunting purposes and the protection of timber. Wood was of such value to ancient Greeks that the city-state of Athens banned its export. The "New Forest," established in 12th-century England, converted cutover land to a royal hunting ground.

Modern natural resource management in the United States began in the late 19th and early 20th centuries, as reflected in the establishment of the Adirondack Forest Reserve, Yellowstone National Park, and our National Forest System. This new approach was concerned with conserving multiple forest resources for sustained use by future generations. The forest management of the period focused on a perpetual, sustained flow of goods and services and was an enlightened contrast to the devastating exploitation of America's forests up to that time.

Natural resource management has continued to evolve. During the middle four decades of this century, the development of the science of ecology and the reemergence of preservation and wilderness values added greatly to the complexity of forest management. In the last decade of the 20th century, natural resource management must contend with goals that range from restoration of long barren former forest land to maintaining primeval forest ecosystems intact and immune from the hand of humans. As we approach the end of the 20th century, the role of natural resource management is no longer simply that practice of best management as determined by the natural resource professional, but also that of managing natural resources within the context of differing agendas of the public—the owners of State and Federal natural resources.

While forest managers struggle to balance often conflicting social, ecological, and economic demands with loosely defined natural resource stewardship responsibilities, they seem only vaguely aware that one of the basic rules of the game may be fundamentally changed. It is understood that distribution, structure, and quantity of forest ecosystems are functions of climate. But, until recently, all sides in disputes over the role and practices of natural resource management implicitly agreed to rules of engagement that ignored potentially significant changes in the main determinant of forest ecosystems—the Earth's climate.

The controversies of recent decades have not really challenged the basic precepts of the now century-old reforms. Rather, they challenge current interpretations and applications that are perceived to focus too heavily on selected resources. The list of resources—ranging from clean air to safe recreation—has grown, and the relative priorities have shifted. Nevertheless, the basic role of natural resource management is still to maintain the productivity, health, and diversity of the vegetative component of forest ecosystems. It is felt that successfully sustaining vegetation will result in successfully sustaining the other forest resources and values.

But how would the role of natural resource managers change if it became impossible to sustain forest structure and function in the event of global environmental change? How would their role change if the perception of direct cause and effect, relating their actions to environmental consequences, were replaced by a view that external environmental change would swamp any management initiated action? How would they adjust to a role in which the impact of their actions on global environmental systems assumed equal importance with the internal effects on the forest ecosystems they manage? Will natural resource managers acknowledge the increased complexity of the science underpinning their decisions and increased uncertainty about the outcome of those decisions? Will scientists present their research results in terms that will be useful to managers?

These are not hypothetical questions. They are the central issues that will define the role of natural resource management in preparing for, helping to mitigate, and adapting to global change in the next century and beyond. They are also questions that drive the Forest Service Global Change Research Program (FSGCRP).

William T. Sommers, Director
Forest Fire and Atmospheric Sciences Research
Washington, D.C.

Executive Summary

The 1992-93 Forest Service Global Change Research Program (FSGCRP) plan describes the main components of Forest Service Research addressing global change. This report focuses on the global change issue from a natural resource perspective, emphasizing an ecosystem approach to studies of terrestrially based renewable resources.

Global change as discussed here encompasses many potential alterations in the Earth's environment, including climate change, increased ultraviolet (UV-B) radiation, air pollution, acidic deposition, and intensified land use. These changes will affect natural resource health and productivity and, consequently, decisions regarding management of forests and range lands. As the research arm of the USDA Forest Service, it is the responsibility of Forest Service Research (FSR) to provide scientific information to help policy makers and land managers develop sound policies in the face of an uncertain future environment. It is with this objective that the FSGCRP was developed.

All FSGCRP projects contribute to one or more of four major program elements, which are described in detail in chapter II. The atmosphere/biosphere gas and energy exchange program element examines the way climate and atmospheric chemistry impact, or are changed by, the biological world. The second program element, Disturbance Ecology, assesses the potential impact that increased occurrences and severity of fire, insects, and disease episodes may have on forest ecosystems. As the third component, ecosystem dynamics focuses on the response of terrestrial or aquatic ecosystems to global change, analyses the plant and animal composition of the system—including threatened and endangered species—evaluates water quality and quantity, and assesses environmental impacts on vegetation and soils. Finally, human activities and natural resource interactions research addresses the way global change will impact human activities and how human activities—through agriculture and resource management—in a changed environment will affect forest and range lands.

Global change will be felt most acutely at regional levels. To assure that its research is based on an ecosystem and regional approach, FSGCRP is conducted through five regional programs and a national coordinating office. The five programs are located in the Pacific, Interior West, Northern, and Southern regions, and at the Forest Products Laboratory. The regional programs contribute to national objectives while focusing on regional needs. For example, the Pacific Region's recent experiences with severe drought, unusual winter storms, and extreme wildfire activity demonstrate its particular sensitivity to climate variation and provide data for a more general understanding of these phenomena. In contrast, the Northern Region's research on the effect of acidic deposition on forest ecosystems can be applied to management decisions in the Northeastern United States but also has relevance to southeastern forests.

Modeling, monitoring, and quality assurance activities are also important components of the FSGCRP and are described in chapters IV, V, and VI, respectively. The program will develop, evaluate, and apply models to determine the impact of global change on forests and the role of forests in a chang-

ing environment. Models will be used both for their predictive potential and to identify knowledge gaps. Several ongoing monitoring programs of the Forest Service will provide baseline information for describing current resource conditions and trends. Data quality assessment activities are being implemented to assure that data produced in this program are of known and documented quality. This will provide a sound scientific basis for the regional and national integration of research results.

FSGCRP has as one of its objectives the provision of scientific information for policy makers and land use managers. As outlined in chapter VII, FSGCRP shares a common goal with the Resource Planning Act (RPA) assessment of identifying current and future forest conditions and alternative policy responses. Plans to share data bases and coordinate modeling efforts with the RPA assessment will strengthen the Forest Service leadership role in assessing the impacts of global change on society.

The Forest Service has worked with other Federal agencies under the Committee on Earth and Environmental Sciences (CEES) structure to develop the U.S. Global Change Research Program. The FSGCRP continues to be active in the process and the program laid out in this report supports CEES goals and objectives. The Forest Service has also been active in Intergovernmental Panel on Climate Change (IPCC) planning and the FSGCRP incorporates knowledge gained in those activities.

I. GLOBAL CHANGE AND THE USDA FOREST SERVICE

By the end of the next century the global average temperature is expected to have increased by 1.5-4.5° C (2.7-8.1° F), according to the Intergovernmental Panel on Climate Change. As carbon dioxide ($C0_2$), methane (CH_4), and other greenhouse gases increase, so too will the impacts of air pollution, increased ultraviolet (UV-B) radiation, and intensified land use. One inevitable result will be rapid ecosystem changes. These changes will compel society to make important and far-reaching decisions regarding the management and allocation of natural resources to adapt to and mitigate global change. As the steward of over 191 million acres of national forests and grassland, the USDA Forest Service is committed to making informed decisions and responsibly implementing them.

Before rational management decisions can be made, however, we need additional information on how forest and rangeland ecosystems will respond to global change. Although we have an extensive understanding of biophysics, hydrology, climate, and ecology, our knowledge base leaves considerable uncertainty regarding the magnitude and timing of integrated ecological effects. In our forecasts of the future structure, distribution, and productivity of ecosystems, we have assumed that climate will not change. With the assumption of an unchanging atmosphere called into question, research is being redirected toward the function of ecosystems stressed by extreme, marginal, and rapidly changing environmental conditions.

Managers are also faced with unprecedented uncertainty in assessing future resource conditions and with unprecedented risk of catastrophic change. With no perfect analogs of global change available from the past, we are forced to make land management decisions based on an array of potential futures and to weigh the consequences of each. One such challenge would be managing resource values in a forest ecosystem that is shifting across legal boundaries and resource allocation zones in response to changing climate.

The Forest Service Global Change Research Program (FSGCRP) is designed to provide a sound scientific basis for making regional, national, and international management and policy decisions regarding forest ecosystems in the context of global change challenges.

In particular, it provides the scientific basis to address three broad questions concerning global change and forest ecosystems:

1. What processes in forest ecosystems are sensitive to physical and chemical changes in the atmosphere?

Or in policy terms: Is there a problem?

2. How will future physical and chemical climate changes influence the structure, function, and productivity of forest and related ecosystems, and to what extent will forest ecosystems change in response to atmospheric changes?

Or in policy terms: How serious is the problem?

3. What are the implications for forest management and how must forest management activities be altered to sustain forest productivity, health, and diversity?

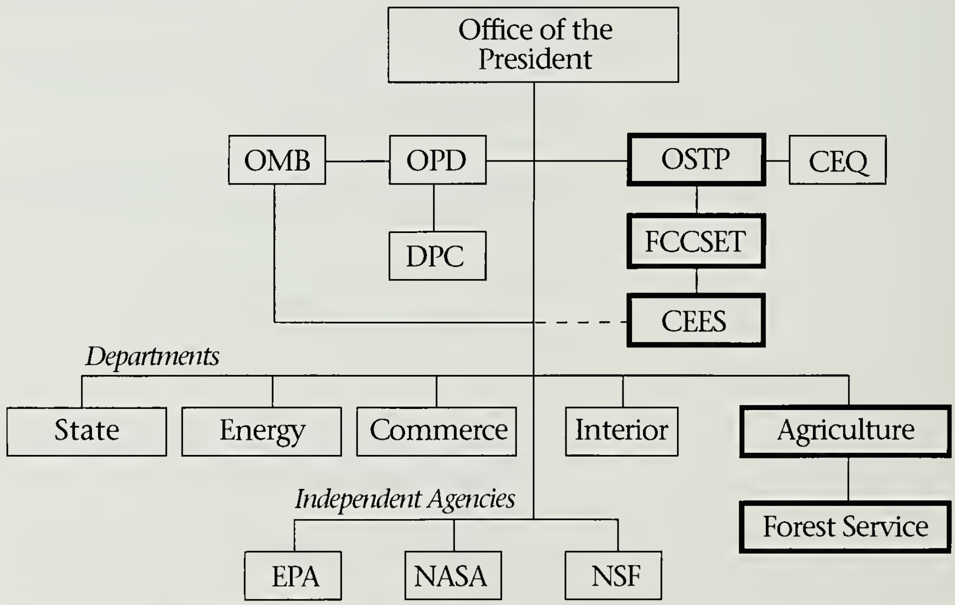
Or in policy terms: What can be done about the problem?

To answer these questions and to provide a sound scientific basis for ecosystem management in a changing global environment, the FSGCRP addresses: the exchange of greenhouse gases and energy between the biosphere and atmosphere; the role of disturbance processes in the function of ecosystems; the ecological processes that will be affected by global change; and human impacts, values, and responses to ecosystem change.

Through participation in the U.S. Department of Agriculture's Global Change Research Program, the FSGCRP is a part of the U.S. Government's Global Change Research Program (USGCRP). USGCRP has been developed under the direction of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President, through the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) and its Committee on Earth and Environmental Sciences (CEES). Its research activities are grouped into seven multi-disciplinary scientific elements: (1) climate and hydrologic systems, (2) biogeochemical dynamics, (3) ecological systems and their dynamics, (4) earth system history, (5) human interactions, (6) solid earth processes, and (7) solar influences. Forest Service research currently supports the first five. The FSGCRP also maintains extensive contacts with international and private programs and, thus, contributes to global change science worldwide.

Healthy forest environments—which produce goods and services as well as satisfy spiritual and aesthetic needs—are critical to our social and economic stability. The FSGCRP objective is to aid the transition from the current environment to a more stable, healthier environment for the future through research, consultation, adaptive management, and an aware and knowledgeable public.

Global Change Executive Branch Organization



II. NATIONAL RESEARCH PROGRAM ELEMENTS

In order to meet its objectives of providing a sound scientific basis for policy and management decisions, FSGCRP research focuses on four scientific program elements: (1) atmosphere/biosphere gas and energy exchange, (2) disturbance ecology, (3) ecosystem dynamics, and (4) human activities and natural resource interactions. Each element has been defined in terms of its general direction and the specific milestones the program hopes to attain. As understanding of global change processes increases, the milestones can be expected to evolve while the general directions remain largely constant.

Atmosphere/ Biosphere Gas and Energy Exchange Research

Atmosphere/Biosphere Gas and Energy Exchange (ATBIOX) research examines the way in which climate and atmospheric chemistry shape and are shaped by the biological world. ATBIOX research is conducted at scales from the regional to the extremely local. It focuses on (1) the carbon cycle and carbon budget with particular attention to the flux of carbon between soils, water, the atmosphere, and the biosphere; (2) greenhouse gas (CO_2, CH_4, N_2O, H_2O) exchanges with terrestrial ecosystems;(3) nutrient cycles and energy flows, and (4) regional and local climate change scenarios. The objective of this research is to understand the flow of gases and energy between the atmosphere and the biosphere, anticipate ways this flow might change, and identify means by which land use and forest management strategies might contribute to mitigating and adapting to global change.

A number of methodologies are applied to ATBIOX research. Measurements of the atmosphere adjacent to plants and plant communities are currently being made to determine biogenic gas fluxes—especially carbon dioxide and methane—and to monitor ozone and acidic deposition at many locations. Soils are monitored to determine trends in carbon storage and to develop an understanding of the processes that control the flux of carbon between soils, aquatic systems, the atmosphere, and the biosphere. Chamber experiments are conducted to determine plant responses to altered physical environments; enhanced carbon dioxide, ozone, and acidic deposition; increased UV-B radiation; and increased insect stress. Changes in and sensitivities of the mechanisms of nutrient cycling by microbes and small soil animals to global change are also studied. Research in these latter two areas shares responsibility with and complements work done in the Ecosystem Dynamics Program area.

Modeling is a significant component of ATBIOX research. Mechanistic models for individual species, functional groupings, and specific ecosystems are under development to describe processes of carbon sequestration and allocation, water balance, and nutrient cycles. The models also predict changes in responses resulting from natural and human induced stresses. Biogeochemical soil models that couple climate to nutrient budgets, soil organisms, soil structure, function, and productivity are being developed. A modeling framework will connect existing and new models at the variety of scales necessary to predict ecosystem responses to climate changes and climate responses to ecosystem changes.

ATBIOX research will lead to a number of results by 1996.

1992-96 Milestones

- *Regional climate change scenarios.* Outputs from coupled ocean atmosphere general circulation models will be organized into scenarios of possible future climates. Projections of the nature and magnitude of potential changes in temperature, humidity, precipitation, and wind in the United States will be published.

- *Local climate scenarios.* Since both disturbances and management can affect microclimate, a capability to generate local climate scenarios must be provided to researchers. This capability may take the form of a computer software package, a centralized facility, or some other mechanism as appropriate.

- *Design of a terrestrial ecosystem modeling framework.* A framework or shell is needed to make possible the integration of terrestrial ecosystems and global climate systems. This shell will provide such a capability for all models supportive of terrestrial ecosystems.

- *Terrestrial carbon budget accounting framework.* A model that incorporates the best data available on carbon storage in U.S. forests and projected carbon consequences of management and land use will be published. The procedures for modeling the carbon consequences of forest management, land-use changes, and climate change scenarios will be upgraded and incorporated into the carbon accounting framework to provide a tool for use in assessing mitigation and adaptation alternatives.

- *Initial quantification of greenhouse gas exchanges with terrestrial ecosystems.* Measurements of CO_2, CH_4, N_2O, H_2O, reactive hydrocarbons, and aerosol exchanges between selected terrestrial ecosystems (boreal forests, peatlands, temperate forests, semiarid woodlands, arid lands, and riparian zones) based on eddy correlation and other technologies will be conducted and published. First generation models will be developed and published.

Disturbance Ecology Research

Fire, insect, and disease disturbances can profoundly affect the health and productivity of ecosystems. Large-scale disturbances may even become natural disasters, as did the Yellowstone fires of 1988 and the northeastern gypsy moth epidemic. Global climate projections suggest that drought cycles, precipitation patterns, temperature extremes, strong winds, and intense storms may change in the future. These climatic factors drive both the occurrence and severity of fire, insects, and disease episodes. To assess the potential impact of disturbance changes on forest ecosystems, the FSGCRP focuses research on disturbance ecology research (DISTUR).

Fire research focuses on changes in frequency and severity of fire weather resulting from global atmospheric changes, the processes by which fire affects the current equilibrium between climate and ecosystems, and the net result of new fire regimes on production of trace gases and particulate matter in the atmosphere.

Research has been initiated to analyze changes in fuel buildup and fire hazard as well as to predict wildland fire activity and emissions with global change. Historical fire occurrence, determined from fire scars on both live and dead

trees, provides a record of fire frequency and severity over a long period of time. Coupling these data with dendroclimatological and other paleoecological pollen data gives a history of fire in transitional ecosystems and its associated climate relations, which are used to project future conditions. Understanding the role of both human-caused and natural fire in ecosystems provides information on how ecosystems recover from major disturbances. Interactions between humans and fire—such as suppression activities, planned use of fire and the urban/wildland interface—are sensitive to climate and are also assessed.

Insect and disease research focuses on how climate change influences the frequency and severity of insect and disease outbreaks. Their importance as a disturbance influence on ecosystems and how those disturbances accelerate ecosystem change are emphasized. In addition, insect and disease epidemics are studied because they may serve as early warnings of changes in ecosystems. Research also addresses the direct effects of climate change on pest organisms as well as how insect and disease organisms function to influence host species stressed by climate and air pollution.

Monitoring of forest health and identification of insect and disease outbreaks will be intensified to provide a database for mechanistic studies. Models of insect and disease disturbance on ecosystem structure and composition are being developed and should be incorporated into tree growth and yield models. In addition, interactions between humans and insects/diseases—such as benefit/cost analysis, suppression activities, and public perception of management strategies—will be assessed.

1992-96 Milestones

- *Fire occurrance mapping.* Potential changes in fire frequency and intensity as a result of climate change will be mapped at the State level of resolution.

- *Pollution impacts mapping.* Potential changes in other disturbances and their interrelationships as a result of climate change and pollution will be mapped at the State level.

- *Biomass burning emissions inventory.* Primary emissions from biomass burning, including a model for the output of forest fire smoke under various climate scenarios, will be inventoried.

- *Disturbance phenomena risk assessments.* Risk assessments of fire disturbance, pollution driven disturbances, and other climate driven disturbances will be conducted.

- *Pest outbreak modeling.* Models of expected changes in pest outbreak frequency under alternate climate scenarios will be developed.

A long-term contribution of the FSGCRP will be to facilitate the maintenance and proper archiving of data sets and sources—tree cores, sample plots, provenance, plantations—that are expected to have lasting value for analyzing global change issues. In conjunction with this, establishment of standards for data quality and analysis techniques will ensure that data collected will be of long-lasting value.

Ecosystem Dynamics Research (ECODYN)

The Ecosystem Dynamics (ECODYN) research component of our mission focuses on the response of terrestrial and aquatic ecosystems—forest, range, and wildland; wetlands, lakes, and rivers—to global change. ECODYN research is conducted primarily at the local and regional levels. It is directed at (1) understanding basic ecosystem processes, such as elemental cycling and responses to a changing physical and chemical environment; (2) determination of plant and animal species composition and the critical characteristics that ensure viable functioning of each component in the whole system; (3) evaluation of water quality and quantity and the impact of changes in these characteristics on biological diversity as well as the role of forests and rangeland in protecting water quantity and quality; and (4) assessment of environmental impacts on vegetation and soil and the resulting effects on ecosystem dynamics.

The objective of this research is to understand and anticipate the ecosystem changes that will result from altered environmental conditions and to understand the sensitivity of key ecosystem processes and components to different levels of stress. Species migration and ecosystem composition changes will be predicted based on climate, weather, and air pollution scenarios derived from general circulation models and other sources. Threshold limits of ecosystem stability and diversity will be determined. Life histories, population dynamics, competitive interactions, and community dynamics of plants and animals under altered environments are being addressed. Attention is also given to threatened, endangered, and sensitive (TES) species.

ECODYN research employs a variety of techniques and methodologies. Long-term investigations of watershed and ecosystem processes in experimental forests and watersheds are an important part of this research element. Observations occur along environmental gradients and across ecotones. Paleoecology is used as a historical base for forest health and productivity. Controlled experiments provide data on genetic resilience to stress and adaptability of individual plants to changing environments. Using the results of experimental research, ecosystem models and resource production models will be developed and applied.

By the mid-1990's ECODYN research will have produced new information and tools for understanding and predicting the response of ecosystems to global change.

1992-96 Milestones

- *Maps of historic forest distribution.* Maps will be developed that depict historic patterns of forest vegetation distribution under past climate conditions for comparison with projections of future climate change.

- *Projections of potential future distribution.* Using future climate and population scenarios, projections of changing landscape level patterns of forest vegetation will be developed and those patterns will be depicted on maps and other media.

- *Projected forest ecosystem composition.* Projections of changes in composition within forest ecosystems due to changing physical and chemical atmospheric conditions will be developed.

Executive Summary

The 1992-93 Forest Service Global Change Research Program (FSGCRP) plan describes the main components of Forest Service Research addressing global change. This report focuses on the global change issue from a natural resource perspective, emphasizing an ecosystem approach to studies of terrestrially based renewable resources.

Global change as discussed here encompasses many potential alterations in the Earth's environment, including climate change, increased ultraviolet (UV-B) radiation, air pollution, acidic deposition, and intensified land use. These changes will affect natural resource health and productivity and, consequently, decisions regarding management of forests and range lands. As the research arm of the USDA Forest Service, it is the responsibility of Forest Service Research (FSR) to provide scientific information to help policy makers and land managers develop sound policies in the face of an uncertain future environment. It is with this objective that the FSGCRP was developed.

All FSGCRP projects contribute to one or more of four major program elements, which are described in detail in chapter II. The atmosphere/biosphere gas and energy exchange program element examines the way climate and atmospheric chemistry impact, or are changed by, the biological world. The second program element, Disturbance Ecology, assesses the potential impact that increased occurrences and severity of fire, insects, and disease episodes may have on forest ecosystems. As the third component, ecosystem dynamics focuses on the response of terrestrial or aquatic ecosystems to global change, analyses the plant and animal composition of the system—including threatened and endangered species—evaluates water quality and quantity, and assesses environmental impacts on vegetation and soils. Finally, human activities and natural resource interactions research addresses the way global change will impact human activities and how human activities—through agriculture and resource management—in a changed environment will affect forest and range lands.

Global change will be felt most acutely at regional levels. To assure that its research is based on an ecosystem and regional approach, FSGCRP is conducted through five regional programs and a national coordinating office. The five programs are located in the Pacific, Interior West, Northern, and Southern regions, and at the Forest Products Laboratory. The regional programs contribute to national objectives while focusing on regional needs. For example, the Pacific Region's recent experiences with severe drought, unusual winter storms, and extreme wildfire activity demonstrate its particular sensitivity to climate variation and provide data for a more general understanding of these phenomena. In contrast, the Northern Region's research on the effect of acidic deposition on forest ecosystems can be applied to management decisions in the Northeastern United States but also has relevance to southeastern forests.

Modeling, monitoring, and quality assurance activities are also important components of the FSGCRP and are described in chapters IV, V, and VI, respectively. The program will develop, evaluate, and apply models to determine the impact of global change on forests and the role of forests in a chang-

ing environment. Models will be used both for their predictive potential and to identify knowledge gaps. Several ongoing monitoring programs of the Forest Service will provide baseline information for describing current resource conditions and trends. Data quality assessment activities are being implemented to assure that data produced in this program are of known and documented quality. This will provide a sound scientific basis for the regional and national integration of research results.

FSGCRP has as one of its objectives the provision of scientific information for policy makers and land use managers. As outlined in chapter VII, FSGCRP shares a common goal with the Resource Planning Act (RPA) assessment of identifying current and future forest conditions and alternative policy responses. Plans to share data bases and coordinate modeling efforts with the RPA assessment will strengthen the Forest Service leadership role in assessing the impacts of global change on society.

The Forest Service has worked with other Federal agencies under the Committee on Earth and Environmental Sciences (CEES) structure to develop the U.S. Global Change Research Program. The FSGCRP continues to be active in the process and the program laid out in this report supports CEES goals and objectives. The Forest Service has also been active in Intergovernmental Panel on Climate Change (IPCC) planning and the FSGCRP incorporates knowledge gained in those activities.

I. GLOBAL CHANGE AND THE USDA FOREST SERVICE

By the end of the next century the global average temperature is expected to have increased by 1.5-4.5° C (2.7-8.1° F), according to the Intergovernmental Panel on Climate Change. As carbon dioxide ($C0_2$), methane (CH_4), and other greenhouse gases increase, so too will the impacts of air pollution, increased ultraviolet (UV-B) radiation, and intensified land use. One inevitable result will be rapid ecosystem changes. These changes will compel society to make important and far-reaching decisions regarding the management and allocation of natural resources to adapt to and mitigate global change. As the steward of over 191 million acres of national forests and grassland, the USDA Forest Service is committed to making informed decisions and responsibly implementing them.

Before rational management decisions can be made, however, we need additional information on how forest and rangeland ecosystems will respond to global change. Although we have an extensive understanding of biophysics, hydrology, climate, and ecology, our knowledge base leaves considerable uncertainty regarding the magnitude and timing of integrated ecological effects. In our forecasts of the future structure, distribution, and productivity of ecosystems, we have assumed that climate will not change. With the assumption of an unchanging atmosphere called into question, research is being redirected toward the function of ecosystems stressed by extreme, marginal, and rapidly changing environmental conditions.

Managers are also faced with unprecedented uncertainty in assessing future resource conditions and with unprecedented risk of catastrophic change. With no perfect analogs of global change available from the past, we are forced to make land management decisions based on an array of potential futures and to weigh the consequences of each. One such challenge would be managing resource values in a forest ecosystem that is shifting across legal boundaries and resource allocation zones in response to changing climate.

The Forest Service Global Change Research Program (FSGCRP) is designed to provide a sound scientific basis for making regional, national, and international management and policy decisions regarding forest ecosystems in the context of global change challenges.

In particular, it provides the scientific basis to address three broad questions concerning global change and forest ecosystems:

1. What processes in forest ecosystems are sensitive to physical and chemical changes in the atmosphere?

Or in policy terms: Is there a problem?

2. How will future physical and chemical climate changes influence the structure, function, and productivity of forest and related ecosystems, and to what extent will forest ecosystems change in response to atmospheric changes?

Or in policy terms: How serious is the problem?

3. What are the implications for forest management and how must forest management activities be altered to sustain forest productivity, health, and diversity?

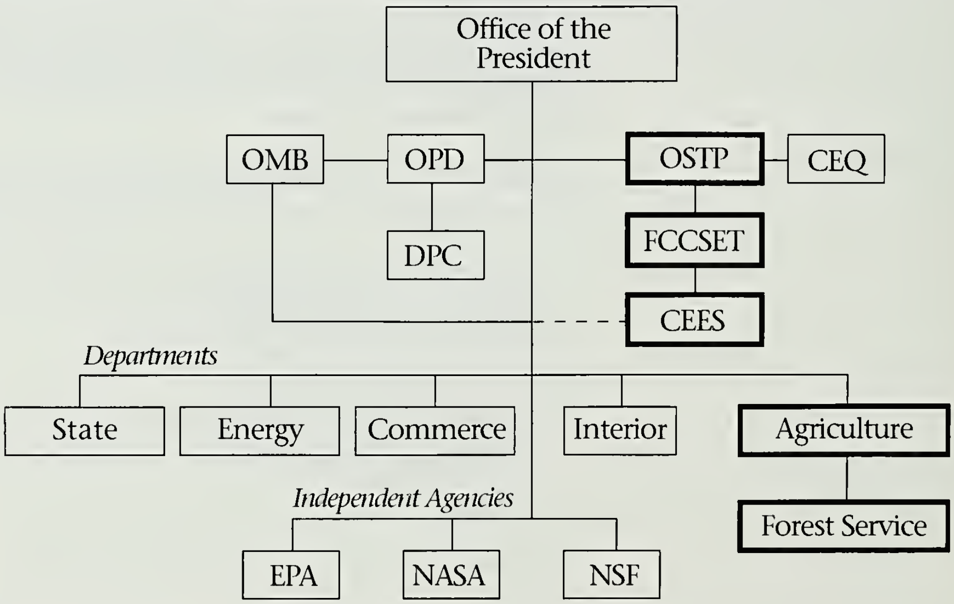
Or in policy terms: What can be done about the problem?

To answer these questions and to provide a sound scientific basis for ecosystem management in a changing global environment, the FSGCRP addresses: the exchange of greenhouse gases and energy between the biosphere and atmosphere; the role of disturbance processes in the function of ecosystems; the ecological processes that will be affected by global change; and human impacts, values, and responses to ecosystem change.

Through participation in the U.S. Department of Agriculture's Global Change Research Program, the FSGCRP is a part of the U.S. Government's Global Change Research Program (USGCRP). USGCRP has been developed under the direction of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President, through the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) and its Committee on Earth and Environmental Sciences (CEES). Its research activities are grouped into seven multi-disciplinary scientific elements: (1) climate and hydrologic systems, (2) biogeochemical dynamics, (3) ecological systems and their dynamics, (4) earth system history, (5) human interactions, (6) solid earth processes, and (7) solar influences. Forest Service research currently supports the first five. The FSGCRP also maintains extensive contacts with international and private programs and, thus, contributes to global change science worldwide.

Healthy forest environments—which produce goods and services as well as satisfy spiritual and aesthetic needs—are critical to our social and economic stability. The FSGCRP objective is to aid the transition from the current environment to a more stable, healthier environment for the future through research, consultation, adaptive management, and an aware and knowledgeable public.

Global Change Executive Branch Organization



II. NATIONAL RESEARCH PROGRAM ELEMENTS

In order to meet its objectives of providing a sound scientific basis for policy and management decisions, FSGCRP research focuses on four scientific program elements: (1) atmosphere/biosphere gas and energy exchange, (2) disturbance ecology, (3) ecosystem dynamics, and (4) human activities and natural resource interactions. Each element has been defined in terms of its general direction and the specific milestones the program hopes to attain. As understanding of global change processes increases, the milestones can be expected to evolve while the general directions remain largely constant.

Atmosphere/ Biosphere Gas and Energy Exchange Research

Atmosphere/Biosphere Gas and Energy Exchange (ATBIOX) research examines the way in which climate and atmospheric chemistry shape and are shaped by the biological world. ATBIOX research is conducted at scales from the regional to the extremely local. It focuses on (1) the carbon cycle and carbon budget with particular attention to the flux of carbon between soils, water, the atmosphere, and the biosphere; (2) greenhouse gas (CO_2, CH_4, N_2O, H_2O) exchanges with terrestrial ecosystems;(3) nutrient cycles and energy flows, and (4) regional and local climate change scenarios. The objective of this research is to understand the flow of gases and energy between the atmosphere and the biosphere, anticipate ways this flow might change, and identify means by which land use and forest management strategies might contribute to mitigating and adapting to global change.

A number of methodologies are applied to ATBIOX research. Measurements of the atmosphere adjacent to plants and plant communities are currently being made to determine biogenic gas fluxes—especially carbon dioxide and methane—and to monitor ozone and acidic deposition at many locations. Soils are monitored to determine trends in carbon storage and to develop an understanding of the processes that control the flux of carbon between soils, aquatic systems, the atmosphere, and the biosphere. Chamber experiments are conducted to determine plant responses to altered physical environments; enhanced carbon dioxide, ozone, and acidic deposition; increased UV-B radiation; and increased insect stress. Changes in and sensitivities of the mechanisms of nutrient cycling by microbes and small soil animals to global change are also studied. Research in these latter two areas shares responsibility with and complements work done in the Ecosystem Dynamics Program area.

Modeling is a significant component of ATBIOX research. Mechanistic models for individual species, functional groupings, and specific ecosystems are under development to describe processes of carbon sequestration and allocation, water balance, and nutrient cycles. The models also predict changes in responses resulting from natural and human induced stresses. Biogeochemical soil models that couple climate to nutrient budgets, soil organisms, soil structure, function, and productivity are being developed. A modeling framework will connect existing and new models at the variety of scales necessary to predict ecosystem responses to climate changes and climate responses to ecosystem changes.

ATBIOX research will lead to a number of results by 1996.

1992-96 Milestones

- *Regional climate change scenarios.* Outputs from coupled ocean atmosphere general circulation models will be organized into scenarios of possible future climates. Projections of the nature and magnitude of potential changes in temperature, humidity, precipitation, and wind in the United States will be published.

- *Local climate scenarios.* Since both disturbances and management can affect microclimate, a capability to generate local climate scenarios must be provided to researchers. This capability may take the form of a computer software package, a centralized facility, or some other mechanism as appropriate.

- *Design of a terrestrial ecosystem modeling framework.* A framework or shell is needed to make possible the integration of terrestrial ecosystems and global climate systems. This shell will provide such a capability for all models supportive of terrestrial ecosystems.

- *Terrestrial carbon budget accounting framework.* A model that incorporates the best data available on carbon storage in U.S. forests and projected carbon consequences of management and land use will be published. The procedures for modeling the carbon consequences of forest management, land-use changes, and climate change scenarios will be upgraded and incorporated into the carbon accounting framework to provide a tool for use in assessing mitigation and adaptation alternatives.

- *Initial quantification of greenhouse gas exchanges with terrestrial ecosystems.* Measurements of CO_2, CH_4, N_2O, H_2O, reactive hydrocarbons, and aerosol exchanges between selected terrestrial ecosystems (boreal forests, peatlands, temperate forests, semiarid woodlands, arid lands, and riparian zones) based on eddy correlation and other technologies will be conducted and published. First generation models will be developed and published.

Disturbance Ecology Research

Fire, insect, and disease disturbances can profoundly affect the health and productivity of ecosystems. Large-scale disturbances may even become natural disasters, as did the Yellowstone fires of 1988 and the northeastern gypsy moth epidemic. Global climate projections suggest that drought cycles, precipitation patterns, temperature extremes, strong winds, and intense storms may change in the future. These climatic factors drive both the occurrence and severity of fire, insects, and disease episodes. To assess the potential impact of disturbance changes on forest ecosystems, the FSGCRP focuses research on disturbance ecology research (DISTUR).

Fire research focuses on changes in frequency and severity of fire weather resulting from global atmospheric changes, the processes by which fire affects the current equilibrium between climate and ecosystems, and the net result of new fire regimes on production of trace gases and particulate matter in the atmosphere.

Research has been initiated to analyze changes in fuel buildup and fire hazard as well as to predict wildland fire activity and emissions with global change. Historical fire occurrence, determined from fire scars on both live and dead

trees, provides a record of fire frequency and severity over a long period of time. Coupling these data with dendroclimatological and other paleoecological pollen data gives a history of fire in transitional ecosystems and its associated climate relations, which are used to project future conditions. Understanding the role of both human-caused and natural fire in ecosystems provides information on how ecosystems recover from major disturbances. Interactions between humans and fire—such as suppression activities, planned use of fire and the urban/wildland interface—are sensitive to climate and are also assessed.

Insect and disease research focuses on how climate change influences the frequency and severity of insect and disease outbreaks. Their importance as a disturbance influence on ecosystems and how those disturbances accelerate ecosystem change are emphasized. In addition, insect and disease epidemics are studied because they may serve as early warnings of changes in ecosystems. Research also addresses the direct effects of climate change on pest organisms as well as how insect and disease organisms function to influence host species stressed by climate and air pollution.

Monitoring of forest health and identification of insect and disease outbreaks will be intensified to provide a database for mechanistic studies. Models of insect and disease disturbance on ecosystem structure and composition are being developed and should be incorporated into tree growth and yield models. In addition, interactions between humans and insects/diseases—such as benefit/cost analysis, suppression activities, and public perception of management strategies—will be assessed.

1992-96 Milestones

- *Fire occurrance mapping.* Potential changes in fire frequency and intensity as a result of climate change will be mapped at the State level of resolution.

- *Pollution impacts mapping.* Potential changes in other disturbances and their interrelationships as a result of climate change and pollution will be mapped at the State level.

- *Biomass burning emissions inventory.* Primary emissions from biomass burning, including a model for the output of forest fire smoke under various climate scenarios, will be inventoried.

- *Disturbance phenomena risk assessments.* Risk assessments of fire disturbance, pollution driven disturbances, and other climate driven disturbances will be conducted.

- *Pest outbreak modeling.* Models of expected changes in pest outbreak frequency under alternate climate scenarios will be developed.

A long-term contribution of the FSGCRP will be to facilitate the maintenance and proper archiving of data sets and sources—tree cores, sample plots, provenance, plantations—that are expected to have lasting value for analyzing global change issues. In conjunction with this, establishment of standards for data quality and analysis techniques will ensure that data collected will be of long-lasting value.

Ecosystem Dynamics Research (ECODYN)

The Ecosystem Dynamics (ECODYN) research component of our mission focuses on the response of terrestrial and aquatic ecosystems—forest, range, and wildland; wetlands, lakes, and rivers—to global change. ECODYN research is conducted primarily at the local and regional levels. It is directed at (1) understanding basic ecosystem processes, such as elemental cycling and responses to a changing physical and chemical environment; (2) determination of plant and animal species composition and the critical characteristics that ensure viable functioning of each component in the whole system; (3) evaluation of water quality and quantity and the impact of changes in these characteristics on biological diversity as well as the role of forests and rangeland in protecting water quantity and quality; and (4) assessment of environmental impacts on vegetation and soil and the resulting effects on ecosystem dynamics.

The objective of this research is to understand and anticipate the ecosystem changes that will result from altered environmental conditions and to understand the sensitivity of key ecosystem processes and components to different levels of stress. Species migration and ecosystem composition changes will be predicted based on climate, weather, and air pollution scenarios derived from general circulation models and other sources. Threshold limits of ecosystem stability and diversity will be determined. Life histories, population dynamics, competitive interactions, and community dynamics of plants and animals under altered environments are being addressed. Attention is also given to threatened, endangered, and sensitive (TES) species.

ECODYN research employs a variety of techniques and methodologies. Long-term investigations of watershed and ecosystem processes in experimental forests and watersheds are an important part of this research element. Observations occur along environmental gradients and across ecotones. Paleoecology is used as a historical base for forest health and productivity. Controlled experiments provide data on genetic resilience to stress and adaptability of individual plants to changing environments. Using the results of experimental research, ecosystem models and resource production models will be developed and applied.

By the mid-1990's ECODYN research will have produced new information and tools for understanding and predicting the response of ecosystems to global change.

1992-96 Milestones

- *Maps of historic forest distribution.* Maps will be developed that depict historic patterns of forest vegetation distribution under past climate conditions for comparison with projections of future climate change.

- *Projections of potential future distribution.* Using future climate and population scenarios, projections of changing landscape level patterns of forest vegetation will be developed and those patterns will be depicted on maps and other media.

- *Projected forest ecosystem composition.* Projections of changes in composition within forest ecosystems due to changing physical and chemical atmospheric conditions will be developed.

Southern Global Change Program

Southern forests are vital to the region and the Nation. Covering approximately 60 percent of the land base in the 12 southeastern and Southcentral States, they support the South's timber, paper, and recreation industries. In addition to their economic benefits, southern forests protect water quality; provide habitat for wildlife, including threatened and endangered species; and provide recreational opportunities for the public. Among the diverse forest ecosystems in the South are upland pine and mixed pine-hardwood forests, pine flatwoods and savannahs; coastal maritime forests, pocosins, cypress-tupelo swamps and mangrove forests; bottomland hardwoods; upland hardwoods; and southern Appalachian spruce-fir forests.

Southern forests are currently subject to numerous physical and chemical stresses. Climate is one stress that can affect forest productivity. Given the warm temperatures of the South, potential evapotranspiration is high, and seasonal and annual water deficits are common. In any given year, local or regional droughts may develop that can reduce tree growth and forest productivity. High temperatures can also reduce tree growth by reducing net photosynthesis.

Chemical climate also affects Southern forests. Ozone, for example, occurs at levels that have been shown to cause foliar injury, physiological alterations, and reductions in growth of several forest species. Preliminary modeling also suggests that the fertility of some Southern soils may be at risk from the combination of short rotations and acidic deposition.

Clearly, predicted changes in the climate and the continued presence of pollutants pose a threat to Southern forests. A warmer climate may be highly unfavorable for spruce-fir forests, which are essentially relics from a cooler age. Warmer, drier conditions may limit the growth of Southern pines and increase the incidence and severity of fire, which has historically played a major role in shaping Southern forests. A changed climate could also have adverse impacts on the forested wetlands of the South.

Another threat to Southern forests is conversion to nonforest uses. In spite of their importance, the acreage of Southern forests has declined over the last 30 years. From 1960 to 1980, the human population of the South increased by 40 percent and it is projected to increase by another 31 percent between 1980 and 2000. As the population has grown, forest lands have given way to urban development and other land uses. These trends are likely to continue and changes in the physical and chemical environment are further risks to the region's forest ecosystems.

The potential for large-scale effects on forests raises questions about socioeconomic impacts on the region, as well as questions about how management practices and policies should be modified in order to adapt to or mitigate these effects. The South may be one area with a high potential for increasing productivity on existing forest lands and planting new forests in order to mitigate climate change by altering the carbon flux from forests. An increased understanding of the interactions between Southern forest ecosystems and the atmosphere will be necessary to meet the challenge of maintaining forest health, productivity, and diversity in the face of global change.

Within the overall scope of the FSGCRP, the mission of the Southern program is to conduct research and monitoring in the Southern region of the United States; to determine the interactive responses among forest ecosystems, atmospheric pollution, and climate change; and to use this knowledge to manage and protect the forest environment and resources. Initially, research is emphasizing pine and pine-hardwood ecosystems. Other high-priority forest types are hardwoods, southern Appalachian spruce-fir, and forested wetlands.

The Southern program focuses largely on four of the environmental factors associated with physical and chemical climate: ozone, carbon dioxide, temperature, and moisture. Much work targets the interactions of multiple environmental stresses. This approach reflects the fact that, in nature, stresses do not occur in isolation. At any one time, individual trees or entire forests must respond to any number of co-occurring stresses. Thus, research on multiple stresses allows us to make greater progress in understanding forest response to pollution and climate change.

Because the relationships between forests, pollutants, and climate are complex, the Southern program is using a hierarchical approach in which studies are conducted at different levels of biological organization. Information from the plant, stand, ecosystem, and regional levels contributes to accomplishing our mission. A variety of research methods will be used, such as controlled exposures of seedlings and mature tree branches to specific environmental stresses, experimental research in soil microcosms in the lab and field, correlational studies of stand and ecosystem functioning, and modeling studies. Models will be used to integrate results, improve interpretation, and make predictions. Models will also be used to "scale up" from one hierarchical level to the next.

In addition to biological research, the Southern program conducts socioeconomic research. Because global change has the potential to alter societal welfare, the program conducts research on the socioeconomic impacts of global change on forest resources of the South. Both timber and nonmarket economic resources will be evaluated. Methods for assessing the socioeconomic impacts of global change are designed to provide information in a form especially useful for policymakers. Other socioeconomic research addresses questions of how forest management practices may be affected and how forest policies may change.

Assessments will play a vital role in the Southern program. Three different types are planned: ecological, resource/risk, and socioeconomic. The information obtained from research on the interactions between forest ecosystems, air pollution, and climate change will provide the foundation for an ecological assessment. The results will be combined with resource information to prepare a resource/risk assessment, which will be used in the development of a socioeconomic assessment and the identification of adaptation and mitigation strategies. These assessments will be used to meet the information needs of scientists, land managers, and policymakers.

In the future, the Southern program plans to expand its biological research on hardwoods and wetlands, initiate research on spruce-fir forests, and conduct research on biodiversity. Forests in the South exhibit a high degree of biologi-

cal diversity. Research in this area will span several forest types and will focus on possible species responses and habitat alterations due to changes in the physical and chemical climate. Issues of particular concern include loss of specialized habitat/refugia, shifts in species ranges, and potential loss of species or populations.

The Southern program is currently supporting research projects that will contribute to our understanding of the issues in the four FSGCRP program elements. Selected projects under each element are listed below.

ATBIOX

- Experimentation and modeling to determine the effects of elevated carbon dioxide, elevated temperature, and altered soil moisture availability on carbon fluxes from loblolly pine trees and stands at three locations across the South.

- Evaluation of existing General Circulation Models to determine the most useful predictors of future climate change and to develop regional climate scenarios for the South.

- Development of a soil temperature model for closed canopy stands.

DISTUR

- A correlational study to evaluate the interaction of climate, insects, and disease in hardwood decline.

- A controlled exposure study to determine the interactions between ozone exposure and the tent caterpillar in sweetgum seedlings.

ECODYN

- Use of tree-ring analysis to detect genetically related differences in the response of loblolly pine to climate in order to better predict the response to altered climate.

- Use of soil microcosms to investigate the effects of climate change on nutrient cycling.

- A field study to investigate the effects of climate on the hydrological cycle and soil processes in a forested wetland.

- Correlational studies in forest stands to investigate the relationships between climate, site factors, and forest productivity.

- A controlled exposure study in the field to determine the interacting effects of drought and ozone on shortleaf pine.

- A controlled exposure study, enclosing entire branches, to determine the effects of elevated carbon dioxide levels, elevated temperature, and altered soil moisture on mature loblolly pine trees and stands.

- A controlled exposure study in the laboratory, coupled with an ambient air field study, to evaluate the effects of elevated carbon dioxide and moisture stress on the competition between several pine and hardwood species.

- Several modeling projects, which will develop tools to evaluate the effects of global change on forest stands and methods to estimate the regional responses to global change.
- A modeling effort linking climate, hydrology, and forest growth and distribution.

HUMANI The Southern program will support socioeconomic research that will evaluate the regional economic impacts of global change on Southern forests, determine the costs and benefits of adapting Southern forest management practices to mitigate the impacts of global change, develop methods to incorporate risk and uncertainty into economic decision models of global change, and explore how forest policies and legislation might change under altered global conditions.

One project currently underway involves linking climate scenarios, predictions of forest productivity changes, and economic forecasts.

Changing Climate

Residents of the Southern United States are usually quick to tell an outsider just how balmy the weather can be. A game of golf or a tennis match on a mild January day is a common and pleasant occurrence in the region. Over the past 5 years, however, the normally warm weather of the South has become more and more uncomfortable. Local weather stations are now recording the hottest and driest years on record.

Areas of the South that normally received two or three light snows each year now receive none. Dogwood flowers and redbud blooms have been appearing a month earlier than usual. Crop failures due to heat and drought have at times forced farmers to request hay shipments from the Midwest. Poultry producers too have suffered as excessive summer heat has threatened their livelihoods.

The recent hot, droughty weather has also taken a toll on commercial forestry operations. Excessive mortality of newly planted loblolly pine seedlings has been bad enough to warrant coverage in newspapers throughout the region. Forest managers report that the problem is serious and costly and gives them concern for the future. They must consider the possibility of irrigation or alternative methods for protecting the vulnerable new seedlings.

Currently, it is impossible for anyone to say if the South's recent warm weather is a temporary happening or part of a global trend. Many more years of data will be needed to determine if the region is experiencing a permanent shift in its climate or if the recent heat waves are simply a short-lived event. Because the consequences, however, are potentially great, resource managers and scientists must keep a watchful eye on the situation and carefully scrutinize the changing weather patterns. Information needs to be developed concerning not only the potential impacts, but also the means for adapting to change.

IV. MODELING

Implicit in global change research is the idea that the Earth system and climate, and their future state, can be understood and predicted. Mathematical models represent current atmospheric and terrestrial conditions and project the changes that could occur as the result of human actions and natural influences. The most widely known and referenced models in global change deliberations are the General Circulation Models (GCM's). Combined with risk analysis and a thorough understanding of the uncertainties inherent in their results, models are one basis for consideration of alternative human activities and selection of appropriate strategies to minimize the negative and maximize the positive effects of global change.

Objectives

The FSGCRP will develop, evaluate, and apply models to address both the impact of global change on forests and the role of forests in a changing environment.

FSGCRP will focus modeling activities to:

1. Improve the understanding of how forest management activities and resource outputs will be affected by a changing climate.

2. Improve the understanding of carbon cycling in trees, forest soils, and wood in service.

3. Evaluate alternative response strategies and options for mitigation and adaptation by predicting system responses to both global change stresses and management actions.

4. Provide an improved characterization of forest and rangeland ecosystems for economic/policy models.

5. Aid in the synthesis and integration of research results and help to identify weaknesses in system understanding.

FSGCRP modeling activities will be conducted by Forest Service scientists and cooperators and managed through its five regional programs. In order to enhance its models and represent forest and related ecosystems on realistic regional to global scales, it will also be linked to similar national and international efforts. As an example of this linkage, FSGCRP will participate with other USGCRP agencies to establish the TERRA Laboratory. Through a small interagency staff, TERRA will provide state-of-the-art computer capability, geographic information system facilities, and programming expertise to visiting scientists. It will also develop or facilitate access to national and international data bases, general circulation model outputs, remote sensing data, and similar data.

Scope

The USGCRP has identified a strategy for bridging the gap between the short-term, large-scale information provided by GCM's and the localized, long-term information produced by ecosystem dynamics models (EDM's). It proposes a "forcing module" to translate GCM outputs to the scales needed by EDMs and an "aggregation module" to transform EDM results to those needed by GCM's.

The FSGCRP modeling effort expands this strategy by connecting social and economic factors with resource outputs from ecosystems. Ecosystem output models (EOM's)—for example, growth and yield tables—are not currently coupled with ecosystem process models. The interactions between EDM's and EOM's requires consideration of disturbance phenomena, water, and climate, all of which interact to affect the outputs. A key component of FSGCRP research will be establishing details of how these phenomena should be linked to provide the proper interfaces between EDM's, forcing module, aggregate module, and EOM's. As these linkages are developed, it is likely that the modules will be incorporated into the redefined structure as well. Defining this linkage will establish guidelines for scientists working on subcomponents and ensure that their results can be aggregated up to the larger system. The aggregation module, yet to be designed, will include both water and disturbance processes and influences to integrate individual ecosystem dynamics models. Ecosystem outputs are also considered from a broad perspective that includes both the significance of the outputs and how management is involved in the sustainability of those outputs.

There is a further need to link human systems to modeling efforts. These systems include resource demands driven by human values and demographic, economic, and political considerations.

V. GLOBAL CHANGE AND RESOURCE MONITORING

Monitoring activities provide the baseline information for describing current resource conditions and trends. Several ongoing monitoring programs of the Forest Service have particular relevance to global change issues. These programs include Forest Inventory and Analysis (FIA), Forest Health Monitoring (FHM), and monitoring activities at long-term ecological research sites.

FIA conducts periodic, comprehensive statewide inventories of forest resource conditions. On average, inventories are conducted every 10 years and have been underway in some areas since the 1930's. FIA data provide a statistically validated overview of resource trends and current conditions and, in cooperation with inventories of national forest lands in the West, cover all forest lands in the United States.

FHM is a new program involving a partnership of Forest Service Research, Forest Service State and Private Forestry, State Forestry Organizations, and the Environmental Protection Agency (EPA). FHM is designed to (1) detect changes in forest resource conditions, (2) evaluate possible causes of changes, and (3) increase our ability to anticipate changes in forest resource conditions. To accomplish this, a three-tiered program of detection monitoring, evaluation monitoring, and intensive site ecosystem monitoring has been established. To complement the broad overview of FIA, FHM integrates more frequent and more detailed observations at sample locations, pest surveys and evaluations, and remote sensing to provide a comprehensive assessment of forest health.

The Forest Service also conducts long-term, intensive monitoring of selected forest ecosystems such as the established programs at the Hubbard Brook Experimental Forest, the Coweeta Hydrological Laboratory, Fraser Experimental Forest, and the H.J. Andrews Experimental Forest. Monitoring and research activities at intensive sites will provide critical input to global change assessments as well as guide design of new research studies contributing to model development.

Existing Forest Service monitoring programs provide a strong foundation for assessing the impacts of global change. In addition to providing accurate baseline and trend data on a wide variety of parameters that have direct relevance to the impacts of global change, these programs will provide efficient and effective monitoring of global change impacts. A high level of coordination within the Forest Service and with other agencies will be required, however, to achieve the needed integration. To achieve this, the Forest Service must consolidate the relevant information on resource conditions by:

- Developing lists of specific parameters currently inventoried, surveyed, and monitored by Forest Service and other agencies, including the duration and frequency of collection.

- Evaluating the applicability of these data to monitoring the potential impacts related to global change.

- Identifying additional parameters needed for the assessment of global change impacts on natural resources.

- Compiling the spatial distribution of current monitoring activities and new additional parameters.

- Developing and applying a geographic information system to provide the ability to analyze numerous resource data sets, including remote sensing data, across large geographic scales.

- Advancing and using remote sensing technology to detect changes in forest condition and distribution.

- Coordinating protocols for data collection and analysis and implementing procedures to assure that the quality of these data is sufficient for their intended use.

A long-term contribution of the FSGCRP will be to facilitate the maintenance and proper archiving of data sets and sources—tree cores, sample plots, provenance, plantations—that are expected to have lasting value for analyzing global change issues. In conjunction with this, establishment of standards for data quality and analysis techniques will ensure that data collected will be of long-lasting value.

Southern Global Change Program

Southern forests are vital to the region and the Nation. Covering approximately 60 percent of the land base in the 12 southeastern and Southcentral States, they support the South's timber, paper, and recreation industries. In addition to their economic benefits, southern forests protect water quality; provide habitat for wildlife, including threatened and endangered species; and provide recreational opportunities for the public. Among the diverse forest ecosystems in the South are upland pine and mixed pine-hardwood forests, pine flatwoods and savannahs; coastal maritime forests, pocosins, cypress-tupelo swamps and mangrove forests; bottomland hardwoods; upland hardwoods; and southern Appalachian spruce-fir forests.

Southern forests are currently subject to numerous physical and chemical stresses. Climate is one stress that can affect forest productivity. Given the warm temperatures of the South, potential evapotranspiration is high, and seasonal and annual water deficits are common. In any given year, local or regional droughts may develop that can reduce tree growth and forest productivity. High temperatures can also reduce tree growth by reducing net photosynthesis.

Chemical climate also affects Southern forests. Ozone, for example, occurs at levels that have been shown to cause foliar injury, physiological alterations, and reductions in growth of several forest species. Preliminary modeling also suggests that the fertility of some Southern soils may be at risk from the combination of short rotations and acidic deposition.

Clearly, predicted changes in the climate and the continued presence of pollutants pose a threat to Southern forests. A warmer climate may be highly unfavorable for spruce-fir forests, which are essentially relics from a cooler age. Warmer, drier conditions may limit the growth of Southern pines and increase the incidence and severity of fire, which has historically played a major role in shaping Southern forests. A changed climate could also have adverse impacts on the forested wetlands of the South.

Another threat to Southern forests is conversion to nonforest uses. In spite of their importance, the acreage of Southern forests has declined over the last 30 years. From 1960 to 1980, the human population of the South increased by 40 percent and it is projected to increase by another 31 percent between 1980 and 2000. As the population has grown, forest lands have given way to urban development and other land uses. These trends are likely to continue and changes in the physical and chemical environment are further risks to the region's forest ecosystems.

The potential for large-scale effects on forests raises questions about socioeconomic impacts on the region, as well as questions about how management practices and policies should be modified in order to adapt to or mitigate these effects. The South may be one area with a high potential for increasing productivity on existing forest lands and planting new forests in order to mitigate climate change by altering the carbon flux from forests. An increased understanding of the interactions between Southern forest ecosystems and the atmosphere will be necessary to meet the challenge of maintaining forest health, productivity, and diversity in the face of global change.

Within the overall scope of the FSGCRP, the mission of the Southern program is to conduct research and monitoring in the Southern region of the United States; to determine the interactive responses among forest ecosystems, atmospheric pollution, and climate change; and to use this knowledge to manage and protect the forest environment and resources. Initially, research is emphasizing pine and pine-hardwood ecosystems. Other high-priority forest types are hardwoods, southern Appalachian spruce-fir, and forested wetlands.

The Southern program focuses largely on four of the environmental factors associated with physical and chemical climate: ozone, carbon dioxide, temperature, and moisture. Much work targets the interactions of multiple environmental stresses. This approach reflects the fact that, in nature, stresses do not occur in isolation. At any one time, individual trees or entire forests must respond to any number of co-occurring stresses. Thus, research on multiple stresses allows us to make greater progress in understanding forest response to pollution and climate change.

Because the relationships between forests, pollutants, and climate are complex, the Southern program is using a hierarchical approach in which studies are conducted at different levels of biological organization. Information from the plant, stand, ecosystem, and regional levels contributes to accomplishing our mission. A variety of research methods will be used, such as controlled exposures of seedlings and mature tree branches to specific environmental stresses, experimental research in soil microcosms in the lab and field, correlational studies of stand and ecosystem functioning, and modeling studies. Models will be used to integrate results, improve interpretation, and make predictions. Models will also be used to "scale up" from one hierarchical level to the next.

In addition to biological research, the Southern program conducts socioeconomic research. Because global change has the potential to alter societal welfare, the program conducts research on the socioeconomic impacts of global change on forest resources of the South. Both timber and nonmarket economic resources will be evaluated. Methods for assessing the socioeconomic impacts of global change are designed to provide information in a form especially useful for policymakers. Other socioeconomic research addresses questions of how forest management practices may be affected and how forest policies may change.

Assessments will play a vital role in the Southern program. Three different types are planned: ecological, resource/risk, and socioeconomic. The information obtained from research on the interactions between forest ecosystems, air pollution, and climate change will provide the foundation for an ecological assessment. The results will be combined with resource information to prepare a resource/risk assessment, which will be used in the development of a socioeconomic assessment and the identification of adaptation and mitigation strategies. These assessments will be used to meet the information needs of scientists, land managers, and policymakers.

In the future, the Southern program plans to expand its biological research on hardwoods and wetlands, initiate research on spruce-fir forests, and conduct research on biodiversity. Forests in the South exhibit a high degree of biologi-

cal diversity. Research in this area will span several forest types and will focus on possible species responses and habitat alterations due to changes in the physical and chemical climate. Issues of particular concern include loss of specialized habitat/refugia, shifts in species ranges, and potential loss of species or populations.

The Southern program is currently supporting research projects that will contribute to our understanding of the issues in the four FSGCRP program elements. Selected projects under each element are listed below.

ATBIOX

- Experimentation and modeling to determine the effects of elevated carbon dioxide, elevated temperature, and altered soil moisture availability on carbon fluxes from loblolly pine trees and stands at three locations across the South.
- Evaluation of existing General Circulation Models to determine the most useful predictors of future climate change and to develop regional climate scenarios for the South.
- Development of a soil temperature model for closed canopy stands.

DISTUR

- A correlational study to evaluate the interaction of climate, insects, and disease in hardwood decline.
- A controlled exposure study to determine the interactions between ozone exposure and the tent caterpillar in sweetgum seedlings.

ECODYN

- Use of tree-ring analysis to detect genetically related differences in the response of loblolly pine to climate in order to better predict the response to altered climate.
- Use of soil microcosms to investigate the effects of climate change on nutrient cycling.
- A field study to investigate the effects of climate on the hydrological cycle and soil processes in a forested wetland.
- Correlational studies in forest stands to investigate the relationships between climate, site factors, and forest productivity.
- A controlled exposure study in the field to determine the interacting effects of drought and ozone on shortleaf pine.
- A controlled exposure study, enclosing entire branches, to determine the effects of elevated carbon dioxide levels, elevated temperature, and altered soil moisture on mature loblolly pine trees and stands.
- A controlled exposure study in the laboratory, coupled with an ambient air field study, to evaluate the effects of elevated carbon dioxide and moisture stress on the competition between several pine and hardwood species.

- Several modeling projects, which will develop tools to evaluate the effects of global change on forest stands and methods to estimate the regional responses to global change.

- A modeling effort linking climate, hydrology, and forest growth and distribution.

HUMANI The Southern program will support socioeconomic research that will evaluate the regional economic impacts of global change on Southern forests, determine the costs and benefits of adapting Southern forest management practices to mitigate the impacts of global change, develop methods to incorporate risk and uncertainty into economic decision models of global change, and explore how forest policies and legislation might change under altered global conditions.

One project currently underway involves linking climate scenarios, predictions of forest productivity changes, and economic forecasts.

Changing Climate

Residents of the Southern United States are usually quick to tell an outsider just how balmy the weather can be. A game of golf or a tennis match on a mild January day is a common and pleasant occurrence in the region. Over the past 5 years, however, the normally warm weather of the South has become more and more uncomfortable. Local weather stations are now recording the hottest and driest years on record.

Areas of the South that normally received two or three light snows each year now receive none. Dogwood flowers and redbud blooms have been appearing a month earlier than usual. Crop failures due to heat and drought have at times forced farmers to request hay shipments from the Midwest. Poultry producers too have suffered as excessive summer heat has threatened their livelihoods.

The recent hot, droughty weather has also taken a toll on commercial forestry operations. Excessive mortality of newly planted loblolly pine seedlings has been bad enough to warrant coverage in newspapers throughout the region. Forest managers report that the problem is serious and costly and gives them concern for the future. They must consider the possibility of irrigation or alternative methods for protecting the vulnerable new seedlings.

Currently, it is impossible for anyone to say if the South's recent warm weather is a temporary happening or part of a global trend. Many more years of data will be needed to determine if the region is experiencing a permanent shift in its climate or if the recent heat waves are simply a short-lived event. Because the consequences, however, are potentially great, resource managers and scientists must keep a watchful eye on the situation and carefully scrutinize the changing weather patterns. Information needs to be developed concerning not only the potential impacts, but also the means for adapting to change.

IV. MODELING

Implicit in global change research is the idea that the Earth system and climate, and their future state, can be understood and predicted. Mathematical models represent current atmospheric and terrestrial conditions and project the changes that could occur as the result of human actions and natural influences. The most widely known and referenced models in global change deliberations are the General Circulation Models (GCM's). Combined with risk analysis and a thorough understanding of the uncertainties inherent in their results, models are one basis for consideration of alternative human activities and selection of appropriate strategies to minimize the negative and maximize the positive effects of global change.

Objectives

The FSGCRP will develop, evaluate, and apply models to address both the impact of global change on forests and the role of forests in a changing environment.

FSGCRP will focus modeling activities to:

1. Improve the understanding of how forest management activities and resource outputs will be affected by a changing climate.

2. Improve the understanding of carbon cycling in trees, forest soils, and wood in service.

3. Evaluate alternative response strategies and options for mitigation and adaptation by predicting system responses to both global change stresses and management actions.

4. Provide an improved characterization of forest and rangeland ecosystems for economic/policy models.

5. Aid in the synthesis and integration of research results and help to identify weaknesses in system understanding.

FSGCRP modeling activities will be conducted by Forest Service scientists and cooperators and managed through its five regional programs. In order to enhance its models and represent forest and related ecosystems on realistic regional to global scales, it will also be linked to similar national and international efforts. As an example of this linkage, FSGCRP will participate with other USGCRP agencies to establish the TERRA Laboratory. Through a small interagency staff, TERRA will provide state-of-the-art computer capability, geographic information system facilities, and programming expertise to visiting scientists. It will also develop or facilitate access to national and international data bases, general circulation model outputs, remote sensing data, and similar data.

Scope

The USGCRP has identified a strategy for bridging the gap between the short-term, large-scale information provided by GCM's and the localized, long-term information produced by ecosystem dynamics models (EDM's). It proposes a "forcing module" to translate GCM outputs to the scales needed by EDMs and an "aggregation module" to transform EDM results to those needed by GCM's.

The FSGCRP modeling effort expands this strategy by connecting social and economic factors with resource outputs from ecosystems. Ecosystem output models (EOM's)—for example, growth and yield tables—are not currently coupled with ecosystem process models. The interactions between EDM's and EOM's requires consideration of disturbance phenomena, water, and climate, all of which interact to affect the outputs. A key component of FSGCRP research will be establishing details of how these phenomena should be linked to provide the proper interfaces between EDM's, forcing module, aggregate module, and EOM's. As these linkages are developed, it is likely that the modules will be incorporated into the redefined structure as well. Defining this linkage will establish guidelines for scientists working on subcomponents and ensure that their results can be aggregated up to the larger system. The aggregation module, yet to be designed, will include both water and disturbance processes and influences to integrate individual ecosystem dynamics models. Ecosystem outputs are also considered from a broad perspective that includes both the significance of the outputs and how management is involved in the sustainability of those outputs.

There is a further need to link human systems to modeling efforts. These systems include resource demands driven by human values and demographic, economic, and political considerations.

V. GLOBAL CHANGE AND RESOURCE MONITORING

Monitoring activities provide the baseline information for describing current resource conditions and trends. Several ongoing monitoring programs of the Forest Service have particular relevance to global change issues. These programs include Forest Inventory and Analysis (FIA), Forest Health Monitoring (FHM), and monitoring activities at long-term ecological research sites.

FIA conducts periodic, comprehensive statewide inventories of forest resource conditions. On average, inventories are conducted every 10 years and have been underway in some areas since the 1930's. FIA data provide a statistically validated overview of resource trends and current conditions and, in cooperation with inventories of national forest lands in the West, cover all forest lands in the United States.

FHM is a new program involving a partnership of Forest Service Research, Forest Service State and Private Forestry, State Forestry Organizations, and the Environmental Protection Agency (EPA). FHM is designed to (1) detect changes in forest resource conditions, (2) evaluate possible causes of changes, and (3) increase our ability to anticipate changes in forest resource conditions. To accomplish this, a three-tiered program of detection monitoring, evaluation monitoring, and intensive site ecosystem monitoring has been established. To complement the broad overview of FIA, FHM integrates more frequent and more detailed observations at sample locations, pest surveys and evaluations, and remote sensing to provide a comprehensive assessment of forest health.

The Forest Service also conducts long-term, intensive monitoring of selected forest ecosystems such as the established programs at the Hubbard Brook Experimental Forest, the Coweeta Hydrological Laboratory, Fraser Experimental Forest, and the H.J. Andrews Experimental Forest. Monitoring and research activities at intensive sites will provide critical input to global change assessments as well as guide design of new research studies contributing to model development.

Existing Forest Service monitoring programs provide a strong foundation for assessing the impacts of global change. In addition to providing accurate baseline and trend data on a wide variety of parameters that have direct relevance to the impacts of global change, these programs will provide efficient and effective monitoring of global change impacts. A high level of coordination within the Forest Service and with other agencies will be required, however, to achieve the needed integration. To achieve this, the Forest Service must consolidate the relevant information on resource conditions by:

- Developing lists of specific parameters currently inventoried, surveyed, and monitored by Forest Service and other agencies, including the duration and frequency of collection.

- Evaluating the applicability of these data to monitoring the potential impacts related to global change.

- Identifying additional parameters needed for the assessment of global change impacts on natural resources.

- Compiling the spatial distribution of current monitoring activities and new additional parameters.

- Developing and applying a geographic information system to provide the ability to analyze numerous resource data sets, including remote sensing data, across large geographic scales.

- Advancing and using remote sensing technology to detect changes in forest condition and distribution.

- Coordinating protocols for data collection and analysis and implementing procedures to assure that the quality of these data is sufficient for their intended use.

A long-term contribution of the FSGCRP will be to facilitate the maintenance and proper archiving of data sets and sources—tree cores, sample plots, provenance, plantations—that are expected to have lasting value for analyzing global change issues. In conjunction with this, establishment of standards for data quality and analysis techniques will ensure that data collected will be of long-lasting value.

VI. DATA QUALITY ASSESSMENT

FSGCRP data quality assessment activities ensure that the data produced for the program are of known and documented quality. Data quality assessment activities will provide a sound scientific basis for the regional and national integration of research results and the assessment of the impact of atmospheric change and increased variability in climate on forest ecosystems. The research and modeling activities planned for global change will provide the basis for making regional, national, and international management and policy decisions for forest and related ecosystems. Accordingly, the quality of the research data and model outputs must be documented to provide a means for comparing the margin of possible data error with the nature of the policy or management problem to be solved. It is the goal of data quality assessment activities to ensure that all environmentally related measurements may be carried out so that uncertainty statements can be made.

The objectives of data quality assessment, which will accomplish this goal are:

1. To document data quality through statistically supported quantitative and qualitative assessments;

2. To ensure comparability of data collection for field and laboratory procedures within and between research projects;

3. To establish criteria for the development and evaluation of models, historical data bases, and socio-economic assessments; and

4. To further develop and implement data quality assessment activities for forestry research, which will assist FSGCRP scientists to do better science and provide a sound scientific basis for making Forest Service management and policy decisions.

The essential features of the data quality assessment activities consist of quality management, quality assurance, and quality control. Quality management establishes program wide policies and procedures that ensure adequate documentation and data quality for all field, analytical, and modeling activities. Quality assurance (QA) implements these polices by establishing and monitoring quality control (QC) procedures including the identification of variability and follow-up control recommendations to improve the accuracy and precision of measurements. QC procedures are implemented by scientists within each project and are designed to produce a sustained reduction of error and document systematic error within statistically defined limits. All three activities comprise the FSGCRP total quality management philosophy in which management policies, research planning, and operating methodology are fully integrated within the national program.

Effective control of data quality within each research project and consistency of data quality among projects is crucial to the regional and national goals of the FSGCRP. In order to achieve these goals a number of data quality assessment tasks have been identified.

1. *Project Study Plans.* All projects are required to submit a combined work and data quality assessment plan. The plan will include a description of objectives, hypotheses, a schedule of tasks and products, statistical methods and analysis, experimental design, variables, power curves, methodology, data quality estimates, and reporting.

2. *Project Performance Reviews.* A well-planned program of project performance reviews is an important feature of data quality assessment. Project reviews verify that measurement systems are operating properly, determine that data quality information is being adequately collected and analyzed, and assess the contribution of each project to over-all program objectives.

3. *Data Quality Reporting.* Data quality statistics will be reported in connection with all research data and model outputs. These statistics will summarize data quality information with tables, figures, graphs, and control charts (indicating accuracy, precision, and completeness). The purpose of this reporting is to provide documentation of the methods and procedures used in the project, to describe the quality of the data collected and analyzed, and to allow for the integration of this information with a summary of research activities of the project.

Forest Service research needs to provide a sound scientific basis for making management and policy decisions. Data quality assessment activities will be integrated into overall Forest Service research goals in order to achieve this objective.

VII. GLOBAL CHANGE AND RESOURCE PLANNING ACT ASSESSMENTS

FSGCRP and the Resource Planning Act (RPA) Assessments have a common goal of assessing current and future resource trends. Each uses various combinations of assumptions about the future to formulate assessments. The FSGCRP focuses on expected changes in atmospheric chemistry and climate, responses of forest ecosystems to such changes, and human interactions with forests. The RPA assessment focuses on resource outputs as affected by alternative supply and demand outlooks, technological changes, and changes in resource productivity. Both programs include periodic assessments as major milestones, have a common need for establishing global change scenarios, and rely on modeling systems for making projections.

Global Change Assessments

Global change assessments synthesize and integrate the results of research and ecological monitoring to address specific policy questions. Models are one tool used for this synthesis and integration: ecological process models scale up from individual organisms to ecosystems to regions and interface with general circulation models; statistical models scale down from global climate projections to regional weather and disturbance events; and various economic and accounting models summarize and track changes in resource conditions and resource outputs. Models developed and used under the FSGCRP will have linkages with climate models, supply/demand models, management decision models, and policy models.

Global change assessments will have four phases:

Phase I—Global Change Scenarios: Projections of global climate change, regional climate changes and episodic disturbances, and air pollution exposure will contain a significant element of uncertainty. Global change assessments will attempt to quantify the uncertainty associated with long-term forecasts of doubled CO_2. This will allow alternative future scenarios for evaluation of possible forest ecosystem responses to be developed.

Phase II—Ecosystem Responses: Ecosystem changes involve individual organism responses, changes in community structure and composition, changes in species distributions, and changes in resource productivity, including timber, water, recreation opportunity, range production, and biological diversity. The second phase of an assessment will analyze sensitivity to climate variability, seeking the answer to such questions as: how much will individual species, communities, and ecosystems change if winter temperatures increase by as much as 5 percent or more?

Phase III—Human Interactions: The third phase of an assessment will address the impacts of global change and ecosystem responses on human populations and activities and determine how altered human activities would impact global change. The analysis will include both impacts on economic activities and impacts on nonmarket human interactions with forests. Analysis of the potential impact of human actions on the landscape and on atmospheric processes will provide background for evaluation of policy options.

Phase IV—Alternative Policy Options: The final phase of an assessment involves identification and evaluation of policy options for mitigating and adapting to global change. Options will include various ways of altering human activities as a means to manage the risks associated with global change. The information will be of use to decisionmakers at various levels: individual land managers, state governments, forest product companies, and national policy makers.

RPA Assessments

RPA assessments follow a longstanding Forest Service tradition of assessing the past, current, and future state of forests. A substantial body of expertise, information management, and modeling systems are in place to support the assessment process. Assessments typically include: (1) a description of the current status of the resource, (2) a projection of supply of and demand for resource outputs, (3) social, economic, and environmental implications of the projections, (4) management opportunities to improve the resource situation, and (5) a description for Forest Service programs and responsibilities. The results of the RPA Assessment are used as the factual basis for formulating future renewable resource management programs.

Linkages Between Global Change and RPA

By sharing data bases and coordinating modeling efforts between the FSGCRP and RPA Programs, the Forest Service will strengthen its leadership role in assessing the impacts of global change on society. Some specific areas of mutual interest include:

1. Identification of plausible global change scenarios through a coordinated Forest Service interaction with general circulation modelers and other global scale modeling efforts.

2. Estimation of expected changes in resource productivity and species composition through synthesis and integration of the results of ecosystem process research.

3. Analysis of the economic impacts of global change and the effects of policies on atmospheric chemistry through linkage of global change models and RPA assessment models.

4. Identification and evaluation of policy options for mitigating or adapting to global change through cosponsored meetings and workshops.

FOREST SERVICE GLOBAL CHANGE RESEARCH PROGRAM

Washington Office—FFASR

Dr. William T. Sommers, *Director*
Dr. Elvia E. Niebla, *National Program Coordinator*
Dr. Michael A. Fosberg, *Response Strategies & Policy*
Ms. Marla Lacayo-Emery, *Research Program Specialist*

USDA Forest Service
P.O. Box 96090
Washington, DC 20090-6090
(202) 205-1561

Pacific Region

Dr. David V. Sandberg
USDA Forest Service
3200 Jefferson Way
Corvallis, OR 97331
(503) 750-7265

Interior West Region

Dr. Douglas G. Fox
USDA Forest Service
240 West Prospect
Fort Collins, CO 80526
(303) 498-1231

Northern Region

Dr. Richard A. Birdsey
USDA Forest Service
5 Radnor Corporate Center, Suite 200
100 Mattsonford Road
Radnor, PA 19087
(215) 975-4092

Southern Region

Ms. Susan Fox
USDA Forest Service
1509 Varsity Drive
Raleigh, NC 27606
(919) 515-3311

Forest Products Laboratory

Mr. John I. Zerbe
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53705
(608) 231-9353

Quality Assurance

Mr. Robert Mickler
USDA Forest Service
1509 Varsity Drive
Raleigh, NC 27606
(919) 515-3311

Regional Research Programs